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Full Length Research Paper

Investigation of groundwater flow heterogeneity in fractured aquifers (Case study: Qusiema area, North Sinai)

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Fractured aquifer is considered as a main promising aquifer in northeastern boarders of Egypt where the Nubian aquifer is deep. The groundwater exploration and evaluation are the main objectives of the present study. Some localities were carefully selected for applying the geophysical techniques to achieve the goal of the study. Both the Vertical Electrical Sounding (VES) and horizontal profiling techniques of direct current resistivity method were applied. The hydrogeological information were analyzed and evaluated using the available software. The Direct Current (DC) resistivity method was applied for delineation the variation of apparent resistivity of sedimentary succession that depends on the density of fractures and cavities. The lateral and vertical distribution of resistivity was mapped to delineate the lateral extension of fractures. Calibration of the resistivity model with the lithologic information, some field measurements carried out for some clearly observed fractured areas helped in identifying the density and the direction of fractures controlling groundwater potentiality. Results indicated that the technique can be applied in similar areas where the carbonate rocks constitute the main reservoir. In the study area, the fractured zone was clearly detected to be extending downward from depth of 15 to 80 m and considered as good aquifer in the area comprising lower resistivity values. Consequently, two different types of water due to different recharge conditions are expected as a result of variation in fractures discontinuity.

Key words: Water, flow, facture, resistivity, aquifer, Sinai.

INTRODUCTION

Egypt has been pressed into the development of Sinai Peninsula, which has high potentials in mineral resources, tourism, and agricultural development. So it is indispensable to evaluate the potential groundwater resources for the development. In this work we outline a research project to study the Eocene aquifer, which is considered to be an important carbonate aquifer in the area of study.

In fractured aquifers, fluid may occur predominantly in an interconnected network of fractures while most of the fluid storage takes place in the relatively low permeability matrix blocks.Flow in fractured aquifers may be described

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by either explicitly or implicitly accounting for the discrete fractures. Groundwater movement in such an aquifer is influenced by many factors that lead to highly spatially variable velocity field. These factors include variable fracture network geometry, small-and large-scale roughness of the fracture walls, presence of fracture filling material. This study aims to verify the fracture zones and its continuities.

Few geological, geophysical and hydrogeological studies has been carried out on this area led to drilling few water wells. Water of these wells differs in quality and quantity due to different reservoir. So, it was considered to study the physical properties of subsurface succession. Since the fractured limestone aquifer is the main aquifer in that area, the research was focused to delineate the fractured zones both laterally and vertically. Although the primary flow pathways in the limestone aquifer are through a network of discrete fractures, these can be delineated through following the fractured zones from of the physical properties such as resistivity. Traditionally the hydrogeology of the limestone has been understood in terms of its representation as an "Equivalent Porous Medium" (EPM) comprises lower resistivity. So, following the direction of these fractures will be able to capture the heterogeneous properties that govern flow within the rock.

Study area

The area of study is located in the northeastern part of Sinai Peninsula, between longitudes 34 15 and 34 20 E and latitudes 30 30 and 30 45 N (Figure 1). It comprises the most populated area in central Sinai near Qussiema, Sabha and Hasana villages, where the main need of water in such area for drinking, domestic and agriculture.

GEOLOGY OF THE AREA

Very meager geological studies were done before, probably because of inaccessibility of the area. The present information came from publications of Sadek (1921), Hume (1962), Said (1962) and Issawi et al. (1994) in addition to the lithological information of the water wells drilled by water resources research institute in the late eighties. According to the Egyptian Geological Survey (EGSMA, 1993) the geology of the Sinai area ranges from Precambrian basement rocks to the Quaternary deposits. The Quaternary sediments cover most the area of study especially the central and northern parts where the thickness of the wadi deposits increase while they decrease in the southern part and the tertiary sediments began to appear and represented by the carbonate rocks of great thickness.

Few individual geological and hydrogeological studies were carried out on the area. Dealing with the geology of the area some regional and local studies were done, from which the works of Geophsica (1963). Some previous distributed studies were carried from these studies the works of Water Resources Research Institute (WRRI, 2006). Limited geophysical studies were carried on the study area.

The surface geology of the study area is described from the geological map of Sinai 1: 500,000 :: shown in Figure 2 executed by the Geological Survey of Egypt (1993). Most of the study area was covered by Pleistocene and Paleocene deposits. Pleistocene deposits are composed of alluvium deposits while Paleocene deposits which so called Esna shale formation is composed of marly shale. The eastern part of the study area is covered by Lower Eocene and Upper Cretaceous rock units. The Lower Eocene is represented by Egma Formation of chalky limestone. The Upper Cretaceous was represented by Sudr, Duwi, Matulla and Wata formations. Sudr Formation is mainly chalk of Maastrichtian age. Duwai formation is composed of alternated carbonate and clastic of Campanian age. Matullah formation is composed of limestone of Conician - Santonian age. Wata formation is composed of dolomitic limestone of Conician- Turonian age.

Field observations, measurements and techniques

The basic principles of the geoelectrical resistivity techniques have been discussed by many authors among them. Flathe (1976), Parasnis (1979), Zohdy et al. (1974), Telfordet et al. (1990) and Apparao (1991). Dobrin (1976) and Zohdy et al. (1974) have considered that, in making resistivity surveys a direct or low frequency current is introduced into the ground via two electrodes (current electrode). The potential difference is measured between a second pair of electrodes (potential electrode). If the four electrodes are arranged in any of the several possible patterns, the current potential measurements may be used to calculate resistivity. The electrical potential (*V*) at any point (P) caused by a point electrode emitting an electric current (*I*) in an infinite homogeneous and isotropic medium of resistivity is given by:

$$V(r) = \frac{I\rho}{4\pi}\frac{1}{R} \quad (1)$$

The derivation of the expression for the potential at the surface and presented in details by Koefoed (1979).

Hence

$$\rho = G\frac{\Delta V}{I} \quad (2)$$

Where G is called the geometric factor of the electrode arrangement

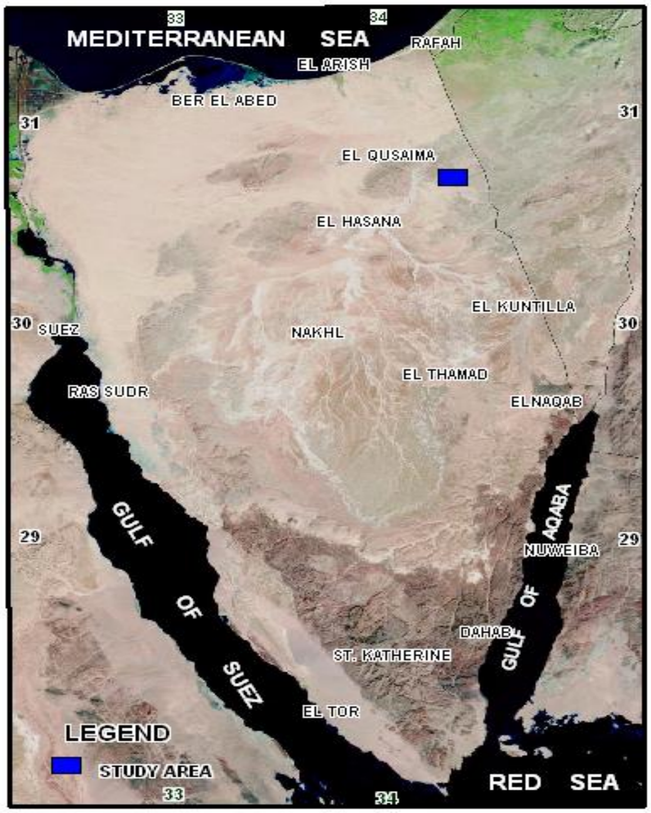

Figure 1. Location of the study area.

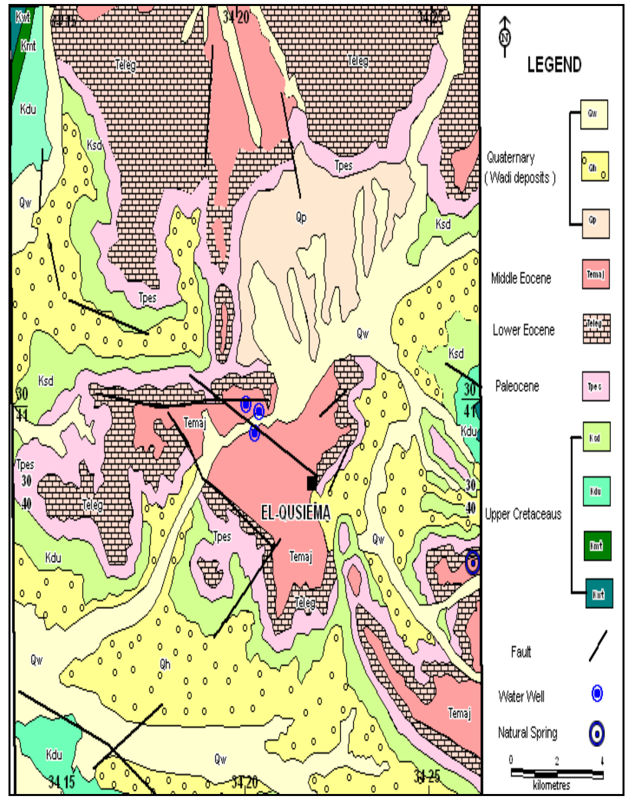

Figure 2. Geologic map of the study area

In case of Schlumberger: $G=\dfrac{\pi R^2}{2r}$

R= half current electrode spacing, r= half potential electrode spacing.

In case of Wenner: G=2π a

a=equaled electrode spacing

If the measurement of ρ is made over a semi-infinite space of homogeneous and isotropic material, the value of ρ computed from Equation (2) will be the true resistivity of that material. However, if the medium is inhomogeneous and/or anisotropic then, the resistivity computed from Equation (2) is called apparent resistivity (ρ_a) (Zohdy et al., 1974).

Theoretically, it is well known that the hard massive limestone comprises higher resistivity values than the fractured. So, calibration of previously saturated fractured area with apparent and true resistivity can help in delineating and mapping the fractured zones and the direction of its extension.

In this study, the Direct Current (DC) geolectrical method was applied for delineation the variation of apparent resistivity of sedimentary units. This succession acts as a conduit for groundwater accumulation depends on the degree of fractures and cavities. The Vertical Electrical sounding (VES) technique was applied to detect the physical properties of the rock sequence laterally and vertically. Schlumberger configuration of electrode array was applied for about 10 measuring points. These measuring points were arranged to cover the study area where the Eocene limestone aquifer is expected to be found at depth of about 100 m. Also, the Wenner configuration was applied to delineate the lateral extension of fractures after assuming a resistivity model for the lithologic succession from the vertical sounding technique. The electrode spacing in Wenner array was chosen according to the expected fractured zones of lower resistivity values that reflected from the VES.

Electrical resistivity measurements were applied using ABEM-AC Terrameter SAS equipment. Using Schlumberger and Wenner electrode array, ten VES-stations were conducted depending on the topographic accessibility in the surveyed areas. The sounding locations were chosen to cover the selected area and the existed wells. Also, horizontal profiling was done along the same profiles connecting VES's. Figure 3 shows the location of VES's and profiles.

Data processing and interpretation

The best fitting of the observed and calculated curves which is the first step of data processing are shown in Figure 4. The data

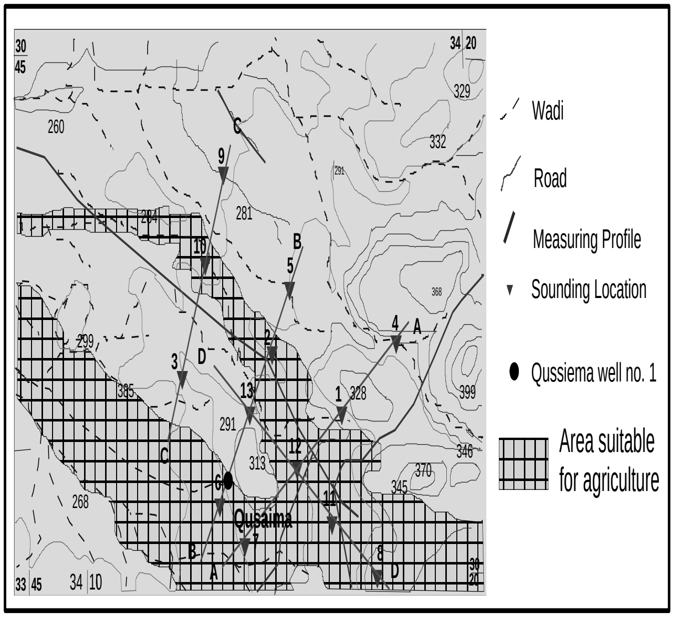

Figure 3. Location of VES's and horizontal profiling lines.

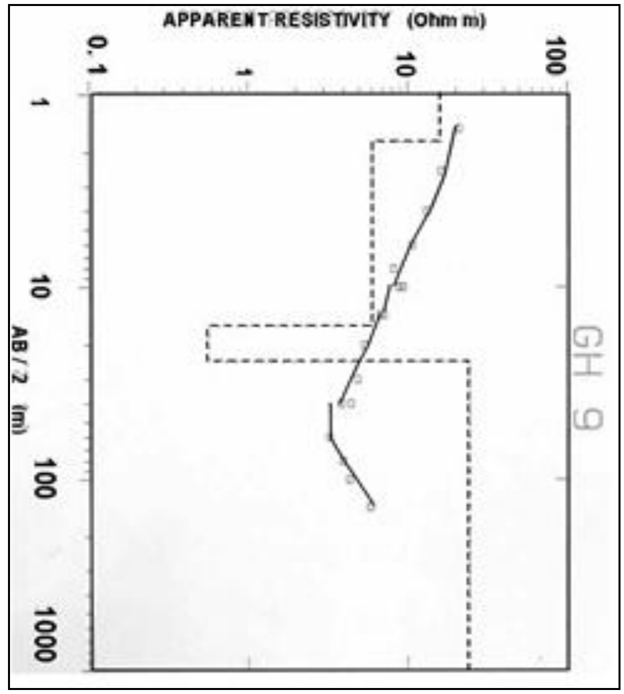

Figure 4. Observed and Calculated resistivity of VES 9.

was processed using 1-D (one-dimensional) modeling program (RESIX-P, 1996). Processing of 1-D initiated first with forward modeling using an initial model based on a simple resistivity-depth transformation of the raw data and geological information from the available boreholes. Then and for getting a better fit, the inverse modeling has been iteratively processed. Inspection of the calculated VES curves reveals that, the number of the interpreted layers varies from three to five layers through at the study area.

Initially, the true resistivity curve for one VES was correlated to lithologic control from the adjacent boreholes (Figure 5). The correlation indicated that relatively lower resistivities (less than 10 Ωm) characterize the topmost dry friable surface cover consists of sand, loam, some gravel and shaley limestone; the higher resistivity values corresponds to the dolometic limestone (non-Fractured) which represents the depth from 7 to 15 m. Another fractured zone extends downward from depth of 15 to 80 m and comprises lower resistivity values as shown in the Figure. Also, these lower resistivity values reflect that the salinity of this zone may be high.

Another calibration was done in the field through Wennermeasurements taken place for some clearly observed fractured areas at which true resistivity was measured with definite array and configuration. These measurements helped in feeding and application of a digital linear filter for transforming vertical electric sounding data (Das and Kumar, 1979), for calculating the number of fractures per unit area. This process was repeated at the different sites to verify the density and the direction of fractures. Analysis of these data and correlating with the resistivity of fractured zones helped in estimating the true resistivity of representative rock at its site location. Results of such analysis were represented in geoelectric sections and iso-resistivity maps.

RESULTS AND DISCUSSION

Qualitative and quantitative interpretation of resistivity data help estimating the smooth and layered model for profiles. A total number of 4 geoelectric cross-sections were constructed, (Figures 6, 7, 8 and 9). These sections each VES. These models were used to construct a number of geoelectric cross sections along measuring indicated that the investigated interval reached about 150 m and was consist of five main geoelectric units reflecting different geologic layer, these units were represented in all cross section as follow:

The first unit: Comprises high resistivity values and thickness varies between 0.5 to 2.5 m. It consists of sands, gravel and loam and the high resistivity values reflect dry, friable sandy layer.

Second unit: It reflects lower resistivity values than the overlaying unit ranging between 2.2 and 22 Ωm and thickness ranges between 3 and 15 m. It represents an extension of the above dry layer but with some shally intercalations. Calibration of the resistivity values of this layer with the borehole date indicated that this unit doesn't contain groundwater along all sections.

Third unit: Comprises higher resistivity values ranges from 79 to 165 Ωm and thickness ranges from 10 to 50 m. Calibration of resistivity data with lithologic information indicated that this unit is considered as hard, dry limestone layer.

Fourth unit: This unit is represented by lower resistivity values ranges from 1.4 to 17 Ωm and great thickness. It is the base of the investigated interval at the site of VES's 1, 5, 6, 7, 9, and 12, while, at VES 4 it has a thickness of about 30 m only. The lower resistivity values of this unit reflect that it is a fractured, water bearing unit of limestone.

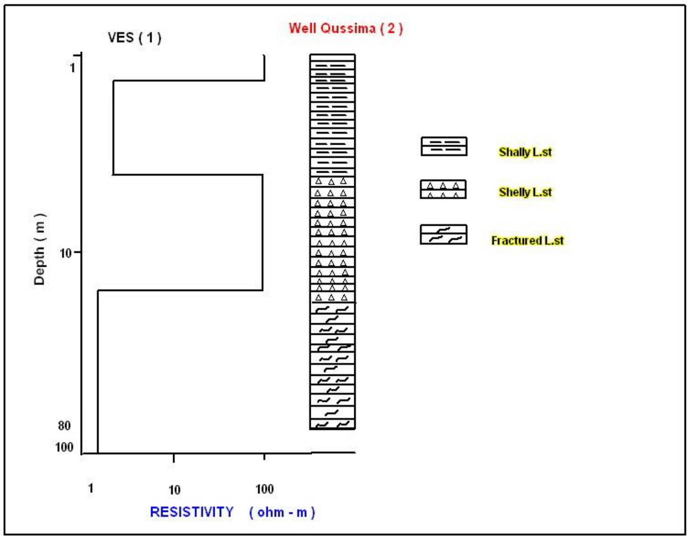

Figure 5. Calibration of resistivity results with lithological data.

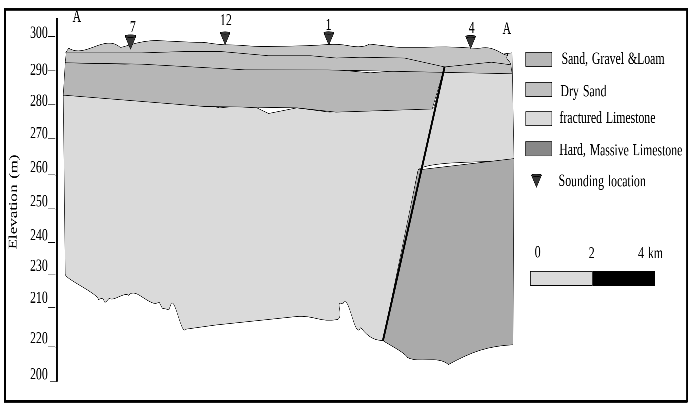

Figure 6. Geoelectric cross-section A-A' in the study area.

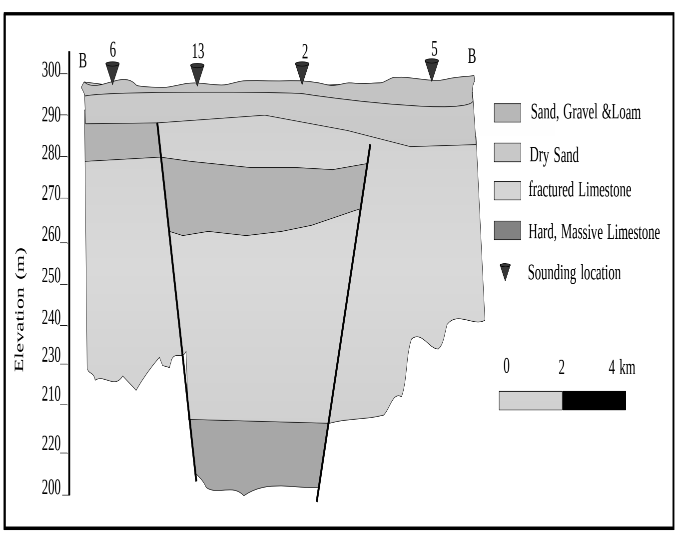

Figure 7. Geoelectric cross-section B-B' in the study area.

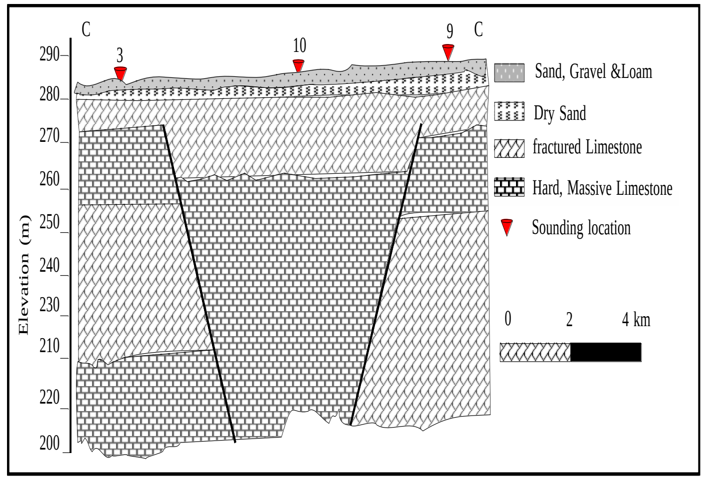

Figure 8. Geoelectric cross-section C-C' in the study area.

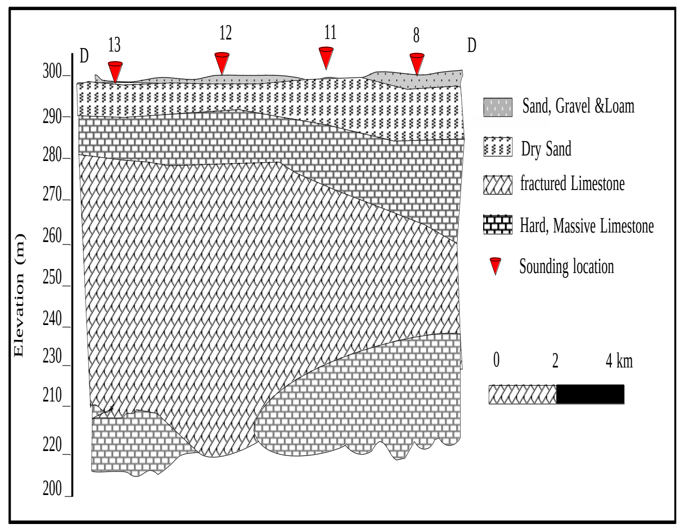

Figure 9. Geoelectric cross-section D-D' in the northern part.

Fifth unit: This unit is considered the base of the investigated interval at the sites of VESs 2, 3, 4, 8, 10, 11 and 12 comprises very high resistivity values (600 Ωm). This high resistivity value may be due to the absence of fractures, as confirmed from the calibration with lithologic information. Calibrating the VES data with the available lithological information and well represented from Wenner results at constant depths of 15 and 50 m indicated two fractured zones; the first is shallow at depth of about 15 m and extends in the northeastern and southwestern parts; the second is deep at depth of about 60 m extends in the central part of the area from east to west and considered the main aquifer in the area.

Iso- parametric maps

The iso-parametric maps are subsurface contour maps

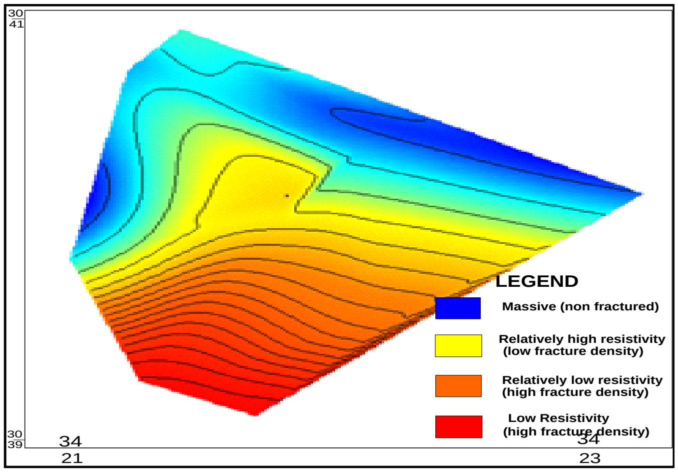

Figure 10. Fracture density contour map at depth of 4 m.

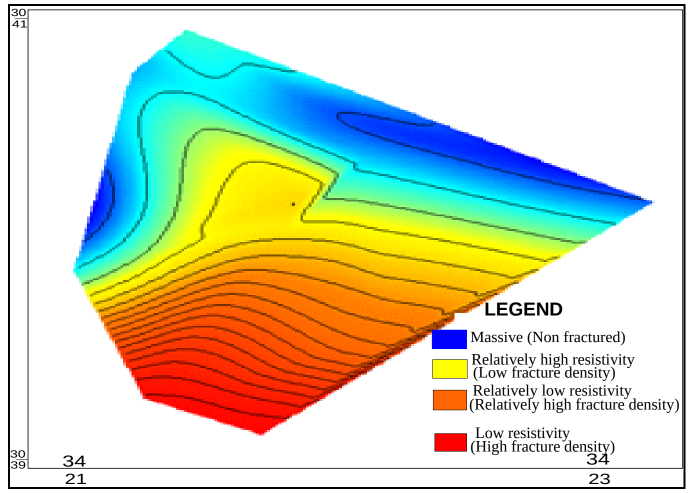

Figure 11. Fracture density contour map at depth of 15 m.

constructed on the available geologic information that can be deduced from the geoelectric cross-sections, boreholes and hydrogeologic data. The purpose of such maps is their use in deduction of the extension and density of fractures at the interested location. The maps are constructed based on the measured apparent resistivity and mainly show the lateral changes of resistivity at different depths. Here, where the purpose of this study is to delineate the direction and density of fractures, these maps were constructed according to the results of calibration of true resistivity data and the intensity of fractures at definite areas where it was exposed

Fracture density contour map at depth 4 m

This map is constructed to show the direction of fractures along the area at depth of about 4 m. It indicates that the intensity of fractures increases from the southeast to the northwest with some discontinuities at the middle of the area. This discontinuity may be due to structures (faults). To the south of the area, the intensity of fractures decreases to less than 3 fractures per each square meter (Figure 10).

Fracture density contour map at depth 15 m

This map reflects the density of fractures at depth 8 m. It indicates that the fracture density increases in the northern half of the area and decreases in the southern half. Generally, there is a gradual increasing in fractures from south to north at this depth. Comparison of this map with the previous one, it was clearly noticed that in the northwestern part, the fractures continue downwards with the same density while in the northeastern part, the density increased. This was clearly confirmed by the resistivity results (Figure 11).

Fracture density contour map at depth 28 m

At the depth of about 28 m, this map reflects different distribution of fractures where the western and eastern edges of the area is still comprising high fracture density , while there is an elongated zone of low density in the central part of the area. This may be due to the effect of the main fault passing through this part of the area as indicated from the geologic map of central Sinai (Figure 12).

Fracture density contour map at depth of 60 m

The map in Figure 13 shows the fracture density distribution at depth of about 60 m where the main groundwater aquifer in the study area is present and most of the productive wells are existed. It represents a wide area of high fracture intensity at the middle of the area from east to west.

Hydrogeological conditions

Aquifer potentiometry

We can classify the water levels according to the condition of its occurrence into natural flowing and unconfined condition. Two natural springs occur within el Qusiema area. Which are located at the upstream portion of Wadi El Gudeirate and Wadi El-Gaifi. These Wadies insisted their channels in the elevated plateau which represents a huge watershed area. These two springs are developed where a Wadi incised the limestone aquifer to the boundary level between limestone and the underlying Paleocene Esna shale. Under these circumstances the groundwater appears as a natural spring. The unconfined aquifer was found to be different; therefore it is difficult to construct a general potentiometeric

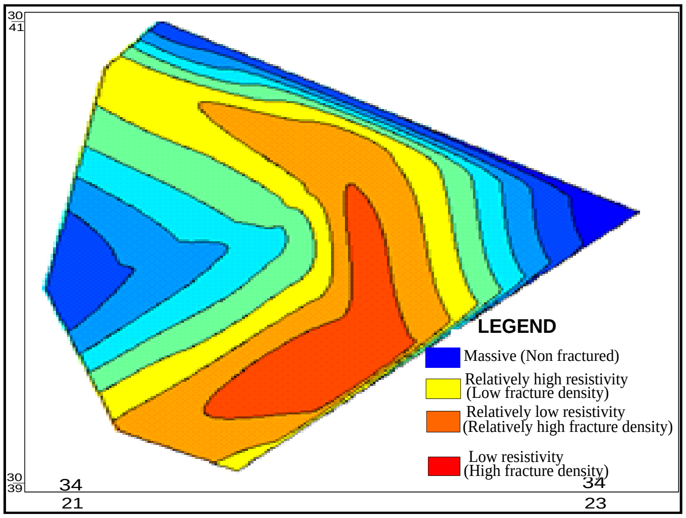

Figure 12. Fracture density contour map at depth of 28 m.

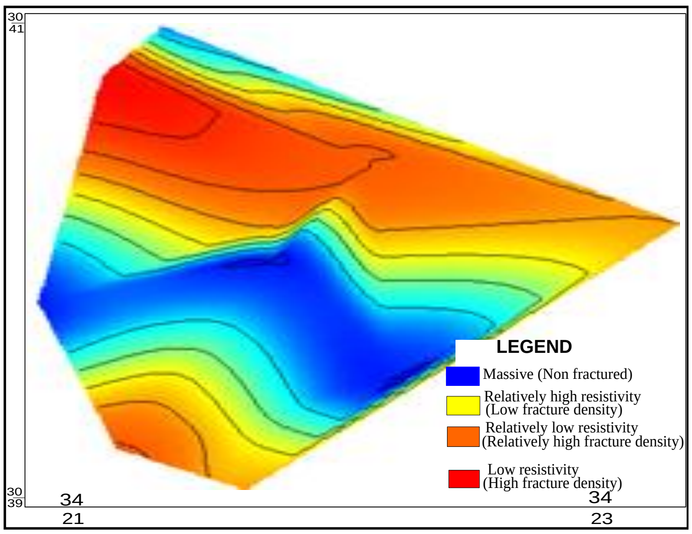

Figure 13. Fracture density contour map at depth 60 m.

surface map. The depth to water varies from 14 to 23 m below ground level. In general the potentiometric surface is in the North West direction.

Hydraulic parameters

The area of study is characterized by the presence of carbonate aquifer especially limestone which is fissured and cracked, so it is so difficult to determine the hydraulic parameters by normal pumping test analyses, consequently, the analyses give approximate values of the hydraulic parameters of the aquifer. By using Jacob method, the Transmissivity (T) was found to be 19.876 m^2/d for well No.1, 172.8 m^2/d for well No.2, and 8 m^2/d for well No.3 (WRRI and JAICA, 1990). By application of aquifer test v 4.2 software on the three cased wells at the area of study, the Transmissivity and Storativity values

Table 1. Transmissivity and Storativity values.

Well No	Transmissivity (m^2/d)	Storativity (S)
1	8.64×10^1	1×10^{-4}
2	8.64×10^1	1×10^{-4}
3	8.64×10^1	1×10^{-4}

were found to be as shown in Table 1. From Table 1 it was found that the Transmissivity and Storativity values were found as the same in the three studied wells due to their occurrence at the same area with the same sedimentary environments and conditions. From the above discussion, it can be concluded that the density of fractures that control groundwater occurrence in carbonate rocks can be delineated through geophysical technique when calibration with real lithologic information is available. Also, verification between the fractured and massive limestone was clearly obtained from the true resistivity.

(1) The general trend of increasing fracture density differs with depth where at shallow depth it increases toward the north and northwest, while at deeper zone the general trend is from north and south to the central part.
(2) As a result of discontinuities downwards in some parts, it is expected to find two different types of water due to different recharge conditions.

Conflict of Interest

The authors have not declared any conflict of interests.

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Review

Critical analysis of existing economic tools available for assessing river water quality

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This review paper critically analyzes the economic literature on the approaches of measuring the environmental benefits. It focuses on the economic methodologies that are available for the evaluation of the effects (social costs and benefits) of environmental changes (degradation/preservation) on river water quality. Further, it shows how the monetary valuations of these effects can have an impact in making of economic policy for creating more efficient water quality management for environmentally sustainable aspects. Over 85 papers were reviewed and it was found that the economic assessment tools were studied independently without comparing the impact of one method over the other. The literature does not provide information on economics of the interventions to protect the river water quality and relate it to the increase in local flora and fauna and decrease in averting costs incurred by local people. Furthermore, the reviewed papers have not economically quantified various pollution control measures to improve water quality in rivers.

Key words: River water quality, river pollution control, monetary valuation, economic policy, environmental benefits.

INTRODUCTION

River systems are one of the most important natural resources which form the basis of human livelihoods. Rivers exhibit extraordinary phenomena, with physical, cultural and psychological expression in human societies; they bring life and death, civilization and devastation, opportunity and risk. These river systems have been an important source for irrigation, potable water, cheap transportation, electricity and other facilities and play an important role in human development. However, huge economic development and population growth result in continuing environmental degradation. Intensification of agriculture, industrialization and increasing urbanization are the most severe driving forces of water quality deterioration in rivers and these river systems are one of the most important vulnerable natural resource.

To value natural environmental resources like river water, it necessitated the need for non-market valuation methods because these resources are neither bought nor

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sold in the market but nonetheless have significant value (Boyer et al., 2004). Valuation of environmental impacts using nonmarket valuation methods has evolved from being completely a U.S activity in 1960s and 1970s to become a very important field also in Europe in 1980s and 1990s. At the same time, nonmarket valuation methods have been applied at an increasing rate in developing countries in Asia, Latin America and Africa (Navrud et al., 1997). Thus monetization of the benefits of water quality improvements is a central component of evaluating the cost-benefit performance of water quality regulations.

The basic concept of economic value incorporates a wide range of measurement techniques than use of market prices. Value theory begins by examining people in situations where they must make choices involving a trade-off, and there are basically two concepts that choice situations present: one in which people give up something to obtain an object of choice (that is, they pay for it), called Willingness to Pay (WTP) and another where they receive compensation in return for giving up an object of choice (that is, they sell it), called Willingness to Accept (WTA) (Hanemann, 1991).

As concern over the deterioration of water quality grows, regular analysis of water quality, diversion of sewerage lines, setting up of industrial wastewater treatment plants to prevent discharge of untreated wastes are some of the positive measures to prevent water pollution. Further effective management of river water quality requires the evaluation of benefits derived from water quality improvements. But as river restoration grows into huge investments a year effort, certainly there will be individuals who will ask whether the benefits of such efforts are worth the costs and hence it is necessary to establish their full value and incorporate this into the decision making process. Widely accepted and often used framework for decision making is Cost Benefit Analysis (CBA). It is an analytical tool conducted by aggregating the total costs and benefits of a project or policy, which represent welfare improvement only if net benefits of costs are positive and an option with highest net benefits is the optimal one, over space and time (Birol et al., 2006). Since 2000, World Health Organization (WHO) has been putting its efforts behind developing and applying approaches to cost–benefit analysis on issues of water, sanitation, hygiene and health. Work is now focusing on the development of methods appropriate for application at the country level to assist in analysis of the cost effectiveness and benefit–cost ratios of water, sanitation and hygiene interventions (Prüss-Üstün et al., 2008). However, values of water resources are not straightforward to estimate for CBA purposes because water bodies are public goods in nature and their values are more complex compared to private goods since water bodies are composed of both use and non-use values (Birol et al., 2006). Capturing the total economic value of water resources is crucial to policy and management decisions, thus enabling society to allocate its scarce economic and environmental resources efficiently.

Various economic methods have been developed to capture the total economic value of environmental resources. Most commonly used are revealed or indirect preference methods (Hedonic Pricing Method (HPM), Travel Cost Method (TCM), Averting Expenditure Method (AEM), and Cost of Illness (COI)) and stated or direct preference methods (Contingent Valuation Method (CVM) and Choice Experiment Method (CEM)).

Aim and objectives

i) Conduct an in depth review of various existing economic tools and techniques for assessing river water quality.
ii) Explain the limitations of these techniques.
iii) Describe the need for economically quantifying various pollution control measures to prevent pollution and improve water quality in rivers.

EXISTING ECONOMIC METHODS

Various researchers have made an attempt to measure the economic value of water quality (Steinnes, 1992; Rogers et al., 2002; Ward et al., 2002; Elsin et al., 2010; Olmstead et al., 2010). This paper is an attempt to review the existing tools the economists use for valuing river water quality for pollution control.

i) Physical Linkage Method [Damage Function Method] and
ii) Behavioural Linkage Method [Direct Methods - Contingent Valuation Method (CVM) and Choice Experiment Method (CEM)] and [Indirect Methods - Averting Expenditure Method (AEM), Travel Cost Method (TCM), Hedonic Pricing (HP) and Cost of Illness (COI)].

Physical linkage method

This measure the benefits based on technical relationship between an environmental resource and user of that resource. Common estimation method is damage function method (Callan et al., 2010).

Damage function method

This uses a functional relationship to capture the link between contaminant and any associated damages. Using this method, incremental benefits are measured as reduction in damages arising from policy-induced decrease in contaminant. This damage reduction is then monetized to obtain the value of benefits brought about by the policy. (Callan et al., 2010).

Behavioural linkage method

Direct methods

These are also called Stated Preference Methods. These valuation methods have been developed to determine the economic benefits of valuing those environmental resources that are not traded in any market, including surrogate ones like water bodies. The commonly used direct methods are Contingent Valuation Method (CVM) and Choice Experiment Method (CEM).

a) Contingent valuation method: Contingent valuation method (CVM) has become a popular way of placing a monetary value on various aspects of the environment with the aim of determining whether the benefits of a proposed project outweigh the costs. The CVM has risen to prominence among these tools (Spash, 2000). With CVM, valuation is dependent or 'contingent' upon a hypothetical situation or scenario whereby a sample of the population is interviewed and individuals are asked to state their maximum WTP (or minimum willingness to accept (WTA) compensation) for an increase, or decrease, in the level of environmental quantity or quality (Birol et al., 2006). The contingent valuation surveys have been conducted by several researchers to see how people were willing to pay for improvements in river water quality (Carson et al., 1993; Kwak et al., 1994; Douglas et al., 1999; Loomis et al., 2000; Turpie et al., 2001; Alam, 2006; Imandoust et al., 2007; Monarchova et al., 2009; Nallathiga et al., 2010; Tu, 2013). CV studies have also been conducted on coastal water quality improvements by Soderqvist (1998), Hokby et al. *(*2003), Hanley et al. *(*2003) and Zhai et al. *(*2009).

Kristrom (1993) explored two commonly used methods to elicit an individual's WTP for a public good in CV studies. According to him, the most preferred method is discrete valuation question where the respondent accepts or rejects a suggested cost for the good. The other method, the traditional one is the CV question which simply asks an individual to state his WTP for the suggested change in the provision of a public good.

An interesting survey carried out by Lindhjem et al. (2009) on the aggregate welfare measures for change in the provision of public goods found it would be higher if the same elicited mean willingness to pay was added up over individuals rather than households. It was revealed that when people were prompted to answer for response unit, an average of 43% decided to state higher willingness to pay than individual willingness to pay, while 52% stated the same willingness to pay. Also more people stated higher household willingness to pay if individual willingness to pay were asked first.

Despite the strengths of CVM regarding its ability to estimate non-use values and evaluate irreversible changes, this method has been criticised for its lack of validity and reliability (Diamond et al., 1994; Carson et al., 2001; Whittington, 2002; Cooper et al., 2004). This is on account of potential problems including information bias (Park et al., 1991; Whitehead et al., 1991; Poe et al., 1997), design bias -starting point bias and vehicle bias (Johansson, 1996; Morrison et al., 2000; Ivehammar, 2009), Yea-saying bias (Remoundou et al., 2009), hypothetical bias (Balistreri et al., 2001; Vossler et al., 2006; Murphy et al., 2010), selection bias (Svento, 1993; Yoo et al., 2001), protest bias (Jorgensen et al., 1999; Strazzer et al., 2003), sequencing bias (Halvorsen 1996), elicitation bias (Loomis, 1997; Loomis et al., 1997; Bohara et al., 2001; Crooker et al., 2004; Farmer et al., 2008; Watanbe et al., 2009), anchoring bias (Frykblom et al., 2000; Arana et al., 2007) and embedding effects (Diamond et al., 1994; Hanemann, 1994). Hypothetical bias contends that respondents may be prepared to reveal their true values but are not capable of knowing these values without participating in a market in the first place. Strategic bias occurs when respondents deliberately under- or overstate their WTP. Respondents may understate their WTP if they believe that the actual fees they will pay for provision of the environmental resources will be influenced by their response to the CV question. Conversely, realizing that payments expressed in a CV exercise are purely hypothetical, respondents may overstate their true WTP in the hope that this may increase the likelihood of a policy being accepted. Yea-saying bias indicates that respondents may express a positive WTP because they feel good about the act of giving for a social good although they believe that the good itself is unimportant while embedding bias implies that WTP is not affected by the scale of the good being offered (Remoundou et al., 2009).

b) Choice experiment method: Choice Experiments (CE) involve eliciting responses from individuals in constructed, hypothetical markets, rather than the study of actual behaviour. The Choice Experiment technique is based on random utility theory and the characteristics theory of value, where environmental goods are valued in terms of their attributes and by making one of these attributes a price or cost term, marginal utility estimates can be converted into willingness-to-pay estimates for changes in attribute levels, and welfare estimates obtained for combinations of attribute changes (Hanley et al., 2006). Researchers (Carlsson et al., 2003; Hanley et al., 2006; Viscusi et al., 2008; Borg et al., 2009; Birol et al., 2010) have applied CE in valuing the improvements in water quality.

Carlsson et al. (2003) conducted CE for valuing wetland attributes in Staffanstorp, southern Sweden and found that attributes like biodiversity and walking facilities were the two greatest contributors to welfare while a fenced waterline and introduction of crayfish decreased welfare.

Birol et al. (2010) used the Choice Experiment method to estimate around 150 randomly selected local public's willingness to pay (WTP) for improvements in the capacity and technology of a pilot scale sewage treatment plant (STP) in Chandernagore municipality, located on the banks of the River Ganga in India. The benefit estimates reported in this study reveal that an average household in the sample would be willing to pay Rs 8.36 per month (Rs 4.82 for high quality of treated water plus 3.54 for high quantity of treated water) in municipal taxes, in order to improve the capacity and technology of the STP. This would amount to Rs 100.32 per annum in additional municipal taxes per household. When aggregated over the entire population (32,939 households), Chandernagore municipality residents' WTP for increasing the capacity of the STP amounts to Rs 3,304,441 per annum. Thus the results reported in this paper are indicative of local public's demand for higher quality and quantity of treated wastewater to minimize the high levels of environmental and health risks in the Ganga.

Alpizar et al. (2001) highlighted the advantages of choice experiments stating that values for each attribute as well as marginal rates between non-monetary attributes can be obtained. According to Johnston (2007), CE results are well suited for benefits transfer because CE are designed to account for variations in environmental resources and site characteristics, as well as potential implications of these variations for willingness to pay. The main objective of the study by Brouwer et al. (2010) was to examine how repeated choice affects preference learning in stated preference experiments. Choice consistency tests suggested that preferences in the choice experiment were stable and coherent. Thus respondents felt significantly more confident and certain about their choice at the end of the choice experiment than they were at the beginning. The research by Taylor et al. (2010) explored the incentive properties of repeated, attribute-based choice questions when subjects are provided with an explicit connection between choices and outcomes. Their study results indicated that the choice-modeling studies that have no explicit provision rule can have a relative error that is more than double the contingent-valuation average error when applied to public goods (96%/39% = 2.5). They also found that when an explicit provision rule discussion is included, the average error in the choice experiments decreased to 57%, which is still larger than that found in contingent valuation studies (57% vs. 39%). These results clearly indicated that the inclusion of a provision rule is necessary for a credible choice-modeling study.

Limitations of CE were discussed by Hanley et al. (1998), Meyerhoff et al. (2008) and Morkbak et al. (2010). Hanley et al. (1998) stated that the principle problems in using the CE method are often the complex nature of statistical/experimental design and the selection of appropriate attributes and levels. Meyerhoff et al. (2008) studied the protest responses in a CE and CV. They used an attitude scale based on respondents' protest beliefs and found a significant negative effect of this attitude on willingness to pay in both methods. However, in one of the two study regions, the effect was found to be weaker in CE than in CV. Morkbak et al. (2010) addressed the issue of defining the levels of the cost variable in Choice Experiments. The main focus was on changes in the maximum price level—the expected choke price affecting consumers' preferences and WTP. The results showed that increasing the maximum price level gave rise to statistically significant increases in the WTP estimates for all attributes. So the high maximum price would indicate to the respondents that the good in question is more valuable, and that they should pay more money to obtain the good. Their results showed that increasing the maximum price level 50%, gave rise to increased WTP estimates of up to 68%, which very well could alter the outcomes of a cost-benefit analysis. So they concluded that setting the choke price can be crucial and hence it deserved attention in the experimental design stage.

Indirect methods

These are also called Revealed Preference Methods. These methods look for related or surrogate markets in which the environmental good is implicitly traded. These methods are suitable for valuing those water resources that are marketed indirectly and are thus only able to estimate their direct and indirect use values. The commonly used indirect methods are Averting Expenditure Method (AEM), Travel Cost Method (TCM), Hedonic Pricing (HP) and Cost of Illness (COI).

a) Averting expenditure method: This method is based on function theory of consumer behaviour and is used to indirectly estimate the willingness to pay for non-marketed commodities like clean water. In the context of water resources, households may respond to increased degradation of water quality in various ways that are generally referred to as averting or defensive behaviours so as to avoid the adverse impacts of water contaminants (Birol et al., 2006). According to Courant et al., (1981), between two differently located but otherwise identical individuals, the difference in their averting expenditures may or may not be a close estimate of their willingness to pay for the preferred location.

There are however important limitations to this method. Individuals may undertake more than one form of averting behaviour in response to an environmental change and the averting behaviour may have other beneficial effects that are not considered explicitly. Furthermore, averting behaviour is often not a continuous decision but a discrete one, depending on the situation. Generally, the averting expenditures does not measure all the costs related to pollution that affect household utility and are therefore only able to provide a lower bound estimate of the true cost of increased pollution (Birol et al., 2006).

Thus if general environment is improved by certain policy initiatives, individual can spend less on substitute goods and this gives an indirect estimate of individual's willingness to pay for associated incremental benefits (Callan et al., 2010).

b) Travel cost method: Travel cost approach is mainly applied to study the recreational value of sites like water bodies, for boating, fishing, watching birds. It uses information about number of trips to particular sites and cost of those trips to infer people's willingness to pay for access to the sites (Boyer et al., 2004). Several researchers have employed travel cost method to measure the welfare effects to changes in water quality and include the work done by Caulkins et al. (1986), Kealy et al. (1986), Hellerstein (1993), Englin et al. *(*1996), Ortacesme et al. (2002), Carr et al. (2003), McKean et al. *(*2005), Shrestha et al. *(*2007) and Hosking (2011). The travel cost method was applied to evaluate the recreational value of the RAMSAR site of the estuary of Massa River (El-Bekkay et al., 2013).

Even though the TCM have been regularly used to determine the value of recreation, a key site attribute often omitted is that of congestion, which describe the number of other individuals encountered during the recreation experience. Researchers (Michael et al., 1997; Boxall et al., 2003; Timmins et al., 2007) studied the recreational congestion. The results of Michael et al. (1997) indicated that failing to account for heterogeneous preferences for congestion by time of visit led to overestimates of the benefits of relieving peak-time congestion, while accounting for expectations raised questions about the validity of the standard optimal use model. Further, the results of this study indicated that the effect of congestion on recreation benefits was best modeled by the difference between actual and expected congestion rather than by simple objective measures of actual congestion.

c) Hedonic pricing: This is a measure of variations in housing prices that reflect the value of local environmental resources like water quality, aesthetics, local flora and fauna. The relationship between land prices and surface water access (both in quantity and quality terms) has been studied in the hedonic framework by Epp et al. (1979), D'arge et al. (1989), Garrod et al. (1994), Lansford et al. *(*1995), Doss et al. *(*1996), Mahan et al. *(*2000), Poor et al. (2007) and Higgins et al. *(*2009). Mahan et al. (2000) used data on more than 14000 home sales in Portland, Oregon metropolitan area to estimate the effect of proximity to wetlands on property values and found that a decrease in the distance to the nearest wetland by 304.8 m from an initial distance of 1 mile resulted in an increase in property value of €371.6.

A limitation of the HPM is that it only measures direct use values of water resources as perceived by the consumers' of the good in which it is implicitly traded. Services such as flood control, water quality improvement, habitat provision for species, and groundwater recharge may provide values that benefit individuals far away, beyond the consumers of the good, which the HPM is unable to capture (Boyer et al., 2004). Leggett et al. (2000) found that hedonic studies of environmental quality are particularly vulnerable to omitted variables bias: the emitters of pollution often have direct effects on the value of nearby properties-for reasons completely unrelated to water quality.

Another limitation discussed by Koundouri et al. (2003) is the effect of selectivity bias on hedonic price analysis. They stated that these valuations can be misleading when the quality characteristics intended for the valuation have sample selection implications and considered the case of land close to seaside that could be used either as an input in agricultural production or for tourist development. The proximity to the sea could reduce the quality of land as an input in agricultural production due to salinization of groundwater supplies, but increased the probability of switching the land usage from agriculture to the lucrative tourism market. Thereafter, the deterioration of groundwater supplies could appear to have a positive effect on the price of agricultural land. They have cautioned that this technique can give rise to misleading conclusions about the effect of an environmental attribute on producers' or consumers' welfare if potential biases from inappropriate sample selection criteria are ignored.

d) Cost of illness method: This method measures the direct (medical costs, nursing care, drugs) and indirect (opportunity) economic costs associated with a disease and estimate the potential savings from the eradication of the disease. This approach also values loss of life based on the foregone earnings associated with premature mortality. The notion is that people should be willing to pay at least as much as the value of the income they would lose by dying prematurely (Remoundou et al., 2009).

Two important limitations of this approach is that it does not consider the actual disutility of those who are ill, nor does it account for the defensive or averting expenditures that individuals may have taken to protect themselves

RESULTS AND DISCUSSION

For this review, the journal papers were collected, collated, reviewed and analyzed intensely to find out the gaps and limitations of various methods were discussed and presented.

In the wake of rampant pollution of water sources, the need of the hour is proper management of water bodies to maintain their purity and sanctity. This paper is an attempt to critically assess and bridge the loopholes of the economic tools for evaluating river water quality and use it to quantify the environmental degradation by monitoring the water quality of the rivers.

The researchers have used the economic assessment tools independently without finding the impact of one method on another. For instance, the water bodies used for recreation are valued using TCM only (McKean et al., 2005; Shrestha et al., 2007; El-Bekkay et al., 2013) without considering the Damage Function and Cost of Illness of local people, which might still result due to microbial contamination of water. Similarly, Hedonic Pricing measures the land prices near water bodies without considering the local flora and fauna in the vicinity of water bodies (Higgins et al., 2009; Mahan et al., 2000). Also the literature does not provide information on economics of the interventions to protect the river water quality and relate it to the increase in local flora and fauna and decrease in averting costs incurred by local people. Further, the literature does not quantify economically various pollution control measures to improve water quality in rivers.

The following discussions are drawn based on the critical review of papers related to Economic tools.

i) Select social discount rates to assess future benefits from policy interventions and carry out a cost - benefit analysis of the interventions.
ii) Develop a mathematical relationship considering various parameters of concern to quantify (in terms of monetary valuation) the pollution abatement investments of the rivers.
iii) Justify investments made for pollution control in the riverine systems through economic quantification.

Conclusions

This review is certainly a step forward in understanding the principles of Environmental Economics by quantifying the impacts of pollution in the rivers and studying the implications of various pollution prevention projects undertaken by the Government, industries and private organizations to improve the quality of water in these rivers. Economic quantification is the basis for assessment of the investments in the form of interventions to protect the river water quality and social benefits like improvements in health of people, local flora and fauna and water quality of rivers. This research is unique because the flaws of existing economic tools are studied for assessing river water quality and this assumes significance in the light of the investments to improve the water quality of these rivers. A major limitation of existing economic tools is the lack of mathematical models for quantifying investments on river water protection. Future work is to combine different economic tools and study the effects of investments made for water protection and pollution control.

Conflict of Interest

The authors have not declared any conflict of interests.

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