Introduction of Lateral Decision Conveying Approach Based Multi Criteria Assessment for Delineation of Ground Water Potentiality

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Abstract— Out lining of potentiality is regarded as the foundation step towards the conservation and management of any resource. Continuous and substantial extraction of ground water has already minimized the quantity of such a useful life supporting flow resource. Delineation of ground water potentiality (GWP) is essential not only to endure the present civilization from the prevailing shadow of water crisis but also to increase the sustainability of water resource development for the generation to come. In the present study efforts are made to scientifically delineate the GWP of selected study area by multi criteria assessment (MCA) of several hydro-geomorphic data and facts. While determining the individual weight and sub weight for MCA, through the study a new approach has been developed in order to strike a balance between accuracy and intricacy.

Key words: Potentiality, Delineation, Sustainability, MCA, Approach, Accuracy

I. INTRODUCTION

Scientists have unanimously agreed upon the fact that presence of water in liquid state is the obvious reason behind the origin, growth and subsistence of life in the planet earth. Among all sources of water now a day man values ground water most than any other alternative because of its multipurpose usage and quick accessibility. As a matter of fact delineation of ground water potentiality helps not only to find out availability of ground water but also to maintain equilibrium between potentiality and exploitation. Such kind of research is considered as the initial step towards the restoration of subsurface water health.

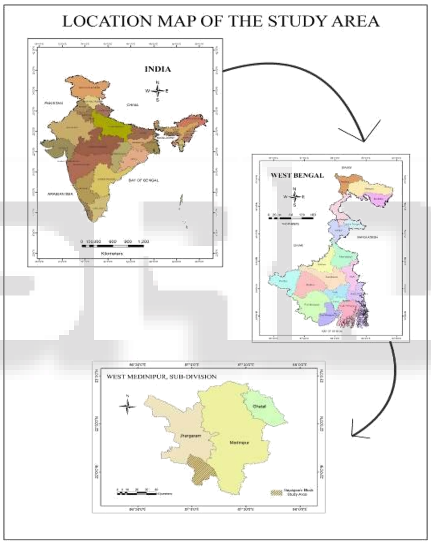
Application of remote sensing (RS) and GIS techniques have provided a whole new look to this kind of study. Remote Sensing along with GIS has emerged as powerful tool in the last few decades to create geospatial inventory on the natural resources. Such inventory comprises of a series of activity i.e. selection of parameters, generation of thematic layers, classification of layers, combination and final output making. Literature shows a no. ground water resource mapping studies have been already conducted on this rationale (Krishnamurthy and Kumar 1996) [1].

However, assigning of weight and sub weight for Multi Criteria Assessment (MCA) based GWP can be done with various approach (Sarup and Tiwari 2011) [2]. In most of these studies determination of weight and sub weight for parameter and individual classes were done by adopting direct scoring approach or on the basis of individual judgment which may bring biasness at times (Ravi Shankar and Mohan 2005) [3]. Few researchers although tried to fix weight and sub weight by accepting the mean score obtained from several expert which may also bring biasness and time factor in consideration. Another scientific scoring process for performing MCA, pairwise comparison of selected parameters along with consistency determination, also used to fulfill the purpose. However this process is too much complex because it not only force the researcher to conduct pairwise comparison twice i.e. first time for weight and then sub weight but also it seeks consistency calculation in both steps. Hence, the present research work has been introducing a new approach, Lateral Decision Conveying (LDC) approach of weight and sub weight determination for MCA.

II. THE STUDY AREA

A. Location

Nayagram, a community development block having an area of 501.44Km^2, located in south western part of West Medinipur district of Paschim Bango, bounded by 22 º 44 ′ N to 22 º 74 ′ N latitude and 88 º 08′ E to 88 º 13 ′ E longitude has been selected for ongoing research rationale.



Map. 1: The study area

B. General Setup

Elevation of the area varies between a maximum of 110 m. in central north to a minimum of 10 m. in south east (from MSL). Annual average maximum and minimum temperatures vary from 32.0° C to 17.4°C. The area receives an annual rainfall around 1615 mm. Murli Nala, one of the tributary of Subarnarekha River, flowing from north east to south west is the main stream of the area. This place is unique for its lateritic soil, undulating topography and natural forest.

C. General Condition of Ground Water

The present study area hydro-geologically deprived from a rich sub surface water resource. In summer most of the dug well dried up and the bore wells go out of order due to severe decrease in ground water level. With the increasing population and prosperity of economic activity the area is ahead of a serious challenge set from scarcity of ground water.

III. DATA USED

To achieve the objectives of the study, both primary as well as secondary raster and vector data was used. These dada are tabulated under.

A. Remote Sensing Data

The specification of the satellite and its products are described in table - 1.

Types of Data	Spatial Resolution	Acquisition Date	Datum
Landsat 7 TM	30 m.	13.02.2010	WGS – 84
DEM	30 m.	02.04.2010	

Table 1: Characteristics of Satellite Data

B. Ancillary Data

Various types of data covering the selected area were used to gather some useful information as specified in table - 2.

Field	Types of Data	Source
Soil	General Soil Map	NBSS & LUP.
Geology	Geological Map	NATMO
Drainage	Drainage Details	SOI Toposheet

Table 2 Characteristics of Ancillary Data

C. Instrumental Data

During ground truth study, GPS instrument was used to obtain the geographical coordinates of the observed field locations.

IV. SOFTWARE'S USED

A. Image Processing

TNT mips PRO 2013 has been used for the preparation of different thematic layers.

B. Classification and Combination

GIS based overlay analysis was done with ARC GIS 10.1

C. Other Doing

Google Earth, MS-Word and MS-Excel.

V. METHODOLOGY

In the present study an integrated approach has been adopted for quantifying as well as analysing GWP zone of the selected area from the selected data and facts. The whole mechanism of ground water resource inventory selected for present paper is depicted step by step with the help of following sub-heads.

A. Selection of parameters

Geospatial data were used as a source of providing base line information about various parameters of GWP (Saraf and Chowdhury, 1998) [4]. The dataset consists of seven thematic layers representing seven different parameters viz. lineament density (Ld), slope (Sl), geomorphology (Gm), Geology (Gl), drainage density (Dd), land use (Lu) and soil characteristics (Sc). These thematic maps were generated under the technical guidelines of Indian National Remote sensing agency and also verified by sample ground truth surveys.

B. Lateral Decision Conveying (LDC) Approach

Determination of weight and sub weight of parameters for MCA can be done with no. of approaches. All the present approaches are either carries authors biased judgment or content with too much complex statistical calculation. Hence the new approach is useful as it maintain a balance between accuracy and simplicity of calculation.

LDC is one kind of Inductive approach where general conception about someone in doing some special activity is standardized on the basis of accuracy in previously done similar kind of performances. In fact this approach has been consciously or unconsciously implemented in various aspects of daily life. As per example plane companies offered pilot with the responsibility of flying airbus after airbus, relying on his or her standard performance in previous occasions and not he or she had to go through skill test before every flight. Here a lateral decision is conveyed that a pilot who proved his skilled before and has a certain amount of experience of fulfilling the job correctly will give the desired output as many times as he asked to do so.

Very often the same approach is also applied in the evaluation of sum although it depends on some condition. Generally evaluation of a sum is done on the basis of two aspects, calculation procedure and answer. After evaluating few sums, providing the conditions that evaluator has a good knowledge of probable answers and same student is successfully doing the same type of sums, evaluator became conveyed a lateral decision that the student has acquired the calculation skill of that type of sums. On the basis of this decision he may skip the evaluation of calculation process by giving focus on only answer of the sums which are already known to him. Now it can be also claimed that judgment of student's ability through OMR answer is also an execution of LDC approach.

In LDC approach based MCA, author himself or only one expert take the responsibility of assigning weight and sub-weight for MCA. At first individual weight of thematic layers were proposed to fix by the help of a pair wise comparison matrix, assigned with the score between 1/9 to 9 focusing on the relative importance (RI) of one criterion over another as shown in table 3 (Hossain and Chowdhury 2009) [5]. These weights were considered as provisional weight until it was not standardized by a consistency test. As in case consistency was found within the range, a lateral decision was conveyed that respective person has gained sufficient knowledge about various aspects of present job as well as acquired masters in scoring skill. Hence sub-weight determination was done by adopting simple ranking method, although it was followed up with consistency test.

RI	Equal	Slight	Strong	Very Strong	Extreme
More	1	3	5	7	9
Less	1	1/3	1/5	1/7	1/9

Table 3 RI of Two Criteria

C. Multi Criteria Assessment

To remove the author's biasness and to handle such large amount of interdisciplinary data multi criteria decision making (MCDM) approach has been implemented (Sani Yahaya 2008) [6]. MCDM is the ability to combine the geographical data and the decision maker's preferences into one dimensional value of alternative decisions (Malczewski 2004) [7]. By the help of WLC, one of the combining techniques of MCDM, summation of the weighted criteria (Su) for each alternative is obtained by multiplying the importance weight of each parameter to the feature score and then summing the products overall attributes. Following standardized formula have been used to combine the parameters along with their sub class -

$$Su = [\sum (Wi * Xi)] \quad ....(1)$$

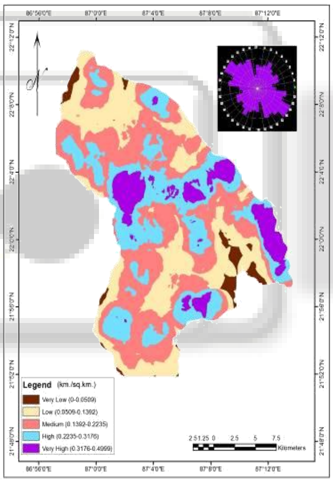
(Where, Wi represents weight of parameters and Xi represents sub weight of individual class).

VI. Elaboration of Parameters

Various thematic layers selected for the identification of ground water potential zone are discussed below.

A. Lineament density

Lineaments are the surface expression of sub surface structural anomaly which developed under the influence of tectonic activity. Due to some special features lineaments perform a decisive role in GWP mapping (Mabee and Hardcastle 2002) [8]. Existences of high volume of loose weathered material under the lineaments not only increase the permeability of surface but also help in retention of ground water.

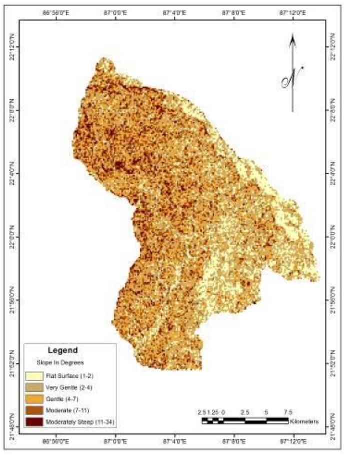


Map. 2: Thematic layer of lineament density

For proper identification of Lineaments filtering was applied to digital image of the study area. Most of them are associated with stream line and various contrastive zones of visible surface features having an orientation in the direction of NW to SE. With the help of lineament vector a lineament density raster with values km. per sq.km was generated. On the basis of extracted values the entire area has been divided into five classes as shown in map 2. Classes were assigned to their internal conduciveness to GWP as in present case the priority maximized with the increase of lineament density

B. Slope

Slope refers to the maximum rate of change in elevation across the surface. It is calculated in degree values. By adopting Wentworth method of slope calculation, a slope map of the study area was prepared (NRSA 1995) [9].

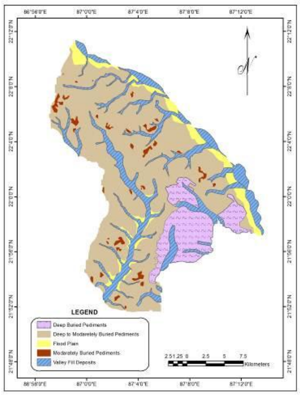


Map. 3: Thematic layer of slope

On the basis of slope value, entire study area has been divided into five classes as shown in map 3. Most of the study area (239.40 Km^2) falls under the category of very gentle slope. Moderately steep slope observed along the watershed boundary whereas flat slope associates with river plain. The relation exists between slope and ground water recharge is inverse one. As the slope decreases surface run off also decreases providing ample opportunity to boost sub surface water.

C. Geomorphology

Geomorphic evidences provide a reliable base for effective planning, development and management of ground water resource of an area (Davis and De Wiest 1966) [10]. After comparing Satellite image of the area with topo-sheet, five distinct geomorphic classes were identified as shown in map 4. These are valley fill deposits, flood plain, deep buried pediments, deep to moderately buried pediments and moderately buried pediments. The unconsolidated deposits consist of mud, silt, sand and small gravels have great ground water potentiality whereas, thin layer of pediments covered with lateritic soil is very much unsuited for GWP due to lack of porosity and permeability.

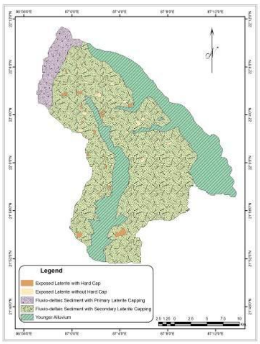


Map. 4: Thematic layer of geomorphic unit.

Valley-fill deposits and flood plain deposits having a textural range from clay to loam occur along the stream bed representing an aerial extent of 96.31$Km.^2$ and 29.35$Km.^2$ respectively. These unconsolidated deposits have great ground water potentiality. Pediments with overlying thickness greater than 120 m. are termed as deep buried pediments. This unit exists in the south eastern parts with an aerial extension of 62.16 Km2 and possesses moderate GWP.

D. Geology

Knowledge of geology helps to set certain limit beyond which with the present level of technological advancement civilization dares to go on. It is an established fact that geological set up of an area plays a vital role in the distribution and occurrence of ground water. Generalized Hydro-geological map of the study area prepared from the base map of Geological Survey of India and enhanced by high resolution ETM satellite image, is shown in map 5.



Map.5: Thematic layer of Hydro-geology

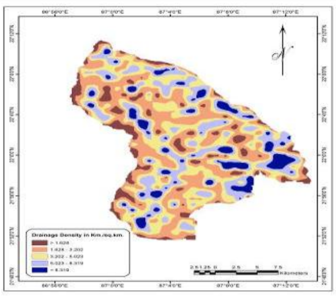
Such map not only helps to identify geologic controls over the various hydrological factors controlling GWP, i.e. surface run off, infiltration and water storage capacity. Among 5 hydro-geological groups identified in the study area, it is found that occurrence of ground water is best associated with younger alluvium group. Two categories namely, exposed laterite with hard cap and exposed laterite without hard cap covering 1.46 % of the entire study area has been identified as zone with very little infiltration and exerts adverse impact on GWP.

E. Drainage density

Drainage density map, outlined in map 6, were prepared by using conventional technique, provides not only a general view of areas surface run off and infiltration characteristics but also represent qualitative assessment of stream segments i.e. water retaining capacity. Such map assigning values with Km. per Km^2 were prepared from the SOI topographical-sheet. To represent drainage density (Dd), following algorithm has been used –

$$Dd = [Sl / A] \ldots\ldots.(2)$$

(Where, Sl = Length of streams in Km.and A = Unit area in Km^2).



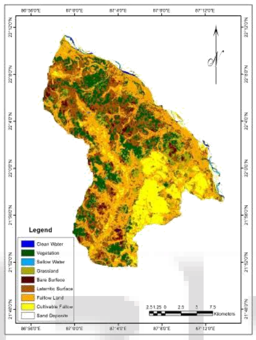
Map. 6: Thematic layer of Drainage density

The high range of Dd values represent the zone having good GWP and low range values stand for just the opposite one i.e. poorly suited to GWP. In terms of hydrological characteristics as the value decreases the zone become less impermeable and become more conducive to surface runoff. On the contrary, as very Dd value are generally associates with water bodies or depressions. Hence the two high classes (4th and 5th) which cover an area about 120.07 Km^2 are identified as best GWP zone and given the best sub weight i.e. value 3.

F. Land use and Land cover (LULC)

Land cover relates to the type of feature present on the surface of the earth whereas land use refers to the human association with land (Lilesand and Kiefer 1979) [11].

The thematic map of LULC as shown in Map 7 has been generated by supervised image classification technique. During this work SOI topographical sheet have been used as reference data source. Entire study area was classified into 9 land use and land cover units based on spectral signature variation of the satellite imagery. The dominant LULC class of the area is forest, followed by cultivable fallow land. Nine LULC classes of the study area were assigned with sub weight from 1 to 3.

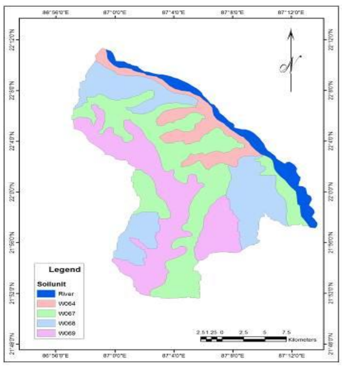


Map. 7: Thematic layer of Land use

G. Soil classification

The amount of ground water recharge, storage and discharge strongly depends on various physical properties of soil (Donahue, Miller and Shickluna1983) [12]. Soil with coarse grain has greater infiltration but it has limited capacity of water retention. On the contrary infiltration goes down as the grain size starts to drop in size simultaneously retention capacity although increases.

On the basis of soil characteristics the study area can be divided into 4 soil categories (map 8) namely, coarse loamy typic ustifluvents (W-64), coarse loamy typic haplsfalfs (W-67), fine loamy ultic paleustalfs (W-68), fine loamy aeric ochraqualfs (W-69) as shown in Map 10. W-69 category covering a total area of % has been given the maximum priority value



Map. 8: Thematic layer of soil classification

VII. OBTAINING WEIGHT AND SUB WEIGHT

A. *Determination of Weight*

This step was highly sensitive and exerts great influence on the ultimate. In order to make the right priority out of more than one alternative a decision supporting method i.e. AHP, an adoption of WLC, developed by Saaty in1980, was used.

The number of pair wise comparisons (Pc) among the parameters was determined by the formula -

$$Pc = [n^* \{(n - 1) / 2\}] \quad ....(3)$$

(Where, n represent the number of responsible parameters).

Thus 21comparison were found in present case. Then author himself assign score between 0.5(least important) to 5(most important) for each pair by considering RI values. These scores for each pair were used as the basic input during the construction of pair wise comparison matrix as shown in table 4. The upper portion of the matrix was filled up by direct scores of pairs whereas lower portion of the matrix was filled up by the reverse scores of same pairs.

	Ld	Sl	Gm	Gl	Dd	Lu	Sc
Ld	1	0.50	1	2.00	3	3	5
Sl	2.00	1	0.50	1	2	3	3
Gm	1.00	2	1	1	2	2	3
Gl	0.50	1	1	1	1	5	3
Dd	0.33	0.50	0.50	1.00	1	0.50	3
Lu	0.33	0.33	0.50	0.20	2.00	1	2
Sc	0.20	0.33	0.33	0.33	0.33	0.50	1
Sum Column	5.366	5.666	4.833	6.533	11.333	15	20

Table 4 Pair-Wise Comparison Matrix

To reach the maximum level of subjectivity, the pair-wise comparison matrix was converted into reciprocal matrix suggested by Sattys Analytical Hierarchy Process (AHP) (Satty 1980) [13]. By help of this matrix, normalized weight for each parameter was obtained as shown in table 5.

Parameter	Normalized Weight	Weight
Lineament density	0.214	21.14
Slope	0.190	19.00
Geomorphology	0.194	19.40
Geology	0.171	17.10
Drainage density	0.096	9.60
Land use	0.085	8.50
Soil Characteristics	0.046	4.60

Table 5 Normalized Matrix With Weight

B. *Consistency of Weight*

Approach has been set to find out the parameter weights for errors in judgment. Presently Saaty's Eigenvector method was used to find out the consistency ratio. If the value of consistency ratio (CR) less than or equal to 0.1, then it is accepted. Value greater than 0.1, requires reconsideration of judgments. CR was calculated by the formula –

$$C.R. = [(C.I.) / (R.I.)] \quad .... (4)$$

(Where, C.I. represents for Consistency index i.e. [(λ max - n) / (n - 1)] and RI, stands for Random index, as shown in table VI).

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.5	0.90	1.12	1.24	1.35	1.41	1.45	1.49

Table 6 Standard Ri

To determine the value of λ max, following sub item value must be computed respectively from table IV. Viz. n√Multiply Row = n (number of parameter i.e. 7) root value of each multiplied row, Priority vector = n√Multiply Row / sum of n√Multiply Row values, Sum column = Sum of each column, Priority row = Sum column * Priority vector.

	n√Multiply Row	Priority Vector	Sum Column	Priority Row
Ld	1.722555471	0.217768	5.366666	1.168690892
Sl	1.511209391	0.19105	5.666666	1.082615229
Gm	1.574610106	0.199065	4.833333	0.962147385
Gl	1.333548306	0.16859	6.533333	1.10145153
Dd	0.742997145	0.093931	11.33333	1.064551384
Lu	0.640959293	0.081031	15	1.215467999
Sc	0.384151156	0.048565	20	0.971301282
Column Total	7.910030867	1.000	68.73333333	7.5662257

Table 7 Consistency Calculation

In the process by summing the Priority row values, λ max achieved for the present matrix were 7.5662257. All these calculation processes are shown in table VII. With the help of λ max C. I. is computed as 0.09437095. Thus the C.R. was found 0.069904407 which was well below the desired level, hence the judgment must be considered absolutely consistent.

C. *Determination of Subweight*

In order to find out the sub-weight i.e. qualitative evaluation of thematic layers, they were classified into five categories on the basis of their individual characteristics to provide favorable condition for prospect of ground water. Sub weight was set between 1(least potential) to 3(most potential) on the basis of direct scoring method rely on expert or author's choice. Thus Sub weight of an individual feature was delineated from the perspective of a broad angle as it was provided by same person; hence it was more subjective and less bias.

Parameters	Rank According to Individual Class					CR
Ld	> 0.059	0.059-0.139	0.139 - 0.223	0.223 - 0.317	< 0.317	0.0253
Rank	1	2	2	3	3	
Sl	Less than 2^0	2^0- 4^0	4^0-7^0	7^0-11^0	More than 11^0	0.0326

Rank	3	2	2	2	1	
Gm	V Fill deposit	Flood Plain	Deep Ped	Deep to mod Ped	Modera-te Ped	0.0196
Rank	3	3	2	1	1	
Gl	Laterite	Laterite hardcap	Fluvio-deltaic I	Fluvio-deltaic II	Younger alluvium	0.0196
Rank	1	1	2	3	3	
Dd	> 1.628	1.628 - 3.202	3.202 - 5.023	5.023 - 8.319	< 3.23	0.0253
Rank	3	3	2	2	1	
Lu	Rock, laterite	Veg, Agriculture	Fallow, Grass	Sand	Water	0.0196
Rank	1	1	2	3	3	
Sc	W – 64	W – 67	W – 68	W – 69	River	0.0326
Rank	2	1	2	3	2	

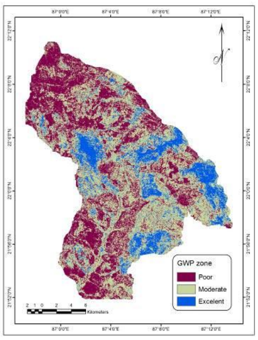
Table 8 Sub Weight With Consistency

VIII. RESULTS

For the delineation of GWP zone, all the thematic layers along with their individual weight and sub-weight were blended under Arc GIS environment. An overlaid analysis was done based on following equation-

GWP = [Ld(wi*xi) + Sl (wi*xi) + Gm(wi*xi) + Gl(wi*xi) + Dd(wi*xi) + Lu(wi*xi) + Sc(wi*xi)]. ……. (5)

The integrated output map was classified into three categories to divide the study area into three qualitative zones in terms of suitability as shown in map 9. Classified categories of the study area in terms of GWP were poor suitable, moderately suitable and excellent suitable (Figure 1). About 36.50% area was classified as poor suitable extending over the places occupied by dry upland. Moderate suitable zone accounts for 49.27%area stretched along river valley and local depressions in all over the study area. Out of total area 71.35 Km^2 (14.23%) were identified excellent suitable zone for ground water potentiality.



Map 9: Thematic layer of ground water potential zone

IX. CONCLUSION

Present study area is suffering from an acute water crisis problem since long time ago. Not only man but also every living being has to toil hard for subsistence in this situation. Unplanned ground water exploitation practice and lack of replenishing knowledge is one of the major reasons behind this aggravated situation.

To get rid of this situation measures should be taken in the direction of enhancing ground water resource storage. Identification of ground water potentiality is one of the preliminary steps in this regard. With the help of methodology of the present paper a new approach to identification of GWP zone is proposed. Present methodology based model as well as data bases will provide a good scope for the development of study areas

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